# OPERATIONAL-EXPERIMENTAL NUMERICAL FORECASTING FOR THE TROPICS

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ABSTRACT

A primitive equation barotropic forecast model is employed independently at 700 mb. and 300 mb. to produce a wind forecast to 36 hr. once daily (from 1200 GMT real data analyses) for the entire tropical belt between 48°N. and 48°S. Experiments have been made in calculating with tropical barotropic forecast models taking values along the northern boundary from a previously calculated Northern Hemisphere forecast. Descriptions of the forecast models and examples and verifications of the forecasts are presented.

## 1. INTRODUCTION

Forecasting winds for the tropical belt between 48°N. and 48°S. with a primitive equation barotropic forecast model [1] on an operational-experimental basis began at the National Meteorological Center (NMC) on April 3, 1967. Forecasts are calculated independently to 36 hr. once per day from 1200 GMT data at 700 mb. and 300 mb. At 24 hr., streamfunction and isotach fields are computed and charts are prepared for transmission on facsimile to Miami and Honolulu and for map discussion and visual verification at NMC. Numerical verifications of the 24-hr. wind forecasts against the verifying analysis are calculated for 17 wind reporting station locations, mostly in the central and western Pacific Ocean area. Also, the 24-hr. persistence forecast is verified for these same 17 locations.

## 2. FORECAST MODEL

The forecast model is the same primitive equation free-surface barotropic model as described in [1]. A 5°-longitude grid on a Mercator projection and rigid walls at 46°N. and 46°S. are employed with cyclic east-west boundaries. The metrical terms have been included in the forecast equations:

$$\frac{\partial u}{\partial t}+m\left[u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g\frac{\partial h}{\partial x}\right]-v\left[u\frac{\partial m}{\partial y}+f\right]=0 \qquad (1)$$

$$\frac{\partial v}{\partial t}+m\left[u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g\frac{\partial h}{\partial y}\right]+u\left[u\frac{\partial m}{\partial y}+f\right]=0 \qquad (2)$$

$$\frac{\partial h}{\partial t}+m\left[u\frac{\partial h}{\partial x}+v\frac{\partial h}{\partial y}+h\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}-\frac{v}{m}\frac{\partial m}{\partial y}\right)\right]=0. \qquad (3)$$

The symbols $x$, $y$, and $t$ are the independent space-time variables, $u$ and $v$ are the eastward and northward velocity components, respectively, $g$ is acceleration of gravity, $f$ is the Coriolis parameter, $h$ is the height of the free surface, and $m$ is the map factor equal to the secant of the latitude. The initial height is obtained from the balance equation that is obtained by appropriate differentiations of equations (1) and (2) and the assumption that the tendency of the divergence is identically zero. The boundary condition for the forecast is the assumption $v=0$ at the wall. Applying this assumption in equations (1) and (2), the boundary conditions for $u$ and $h$ are obtained.

The initial $u$ and $v$ used in calculating the initial height and in the forecast are calculated from a streamfunction defined as,

$$m\nabla^2\psi=\left(\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}+\frac{u}{m}\frac{\partial m}{\partial y}\right), \qquad (4)$$

in which $u$ and $v$ appearing on the right are the respective components from the wind analysis. In the first experimental forecasts made from real data analyses, it was noted that the higher latitude systems moved too slowly at 700 mb. and too fast at 300 mb. To correct these difficulties, the analyzed wind at 700 mb. is multiplied by 1.3 and at 300 mb. is multiplied by the reciprocal of 1.3. These multipliers were derived from Northern Hemisphere approximations of the magnitude of the mean flow, at or near 500 mb. (a mean-flow level), compared with the magnitude of the average flow at 700 mb. and at 300 mb., respectively.

## 3. RESULTS

The numerical verifications of forecasts against analyzed winds for April 1967 at 17 locations have been summarized in two sets. One set is for the Tropics proper and includes nine locations for a region between 20°N. and 20°S.; the other set is for eight locations in latitudes north of 20°N. For the tropical set, the magnitude of the mean vector error is just under 10 kt. for 700 mb. and between 10 and 15 kt. for 300 mb. The forecast is slightly better than persistence for 300 mb. with the opposite being the case for 700 mb. For the higher latitude set the magnitude

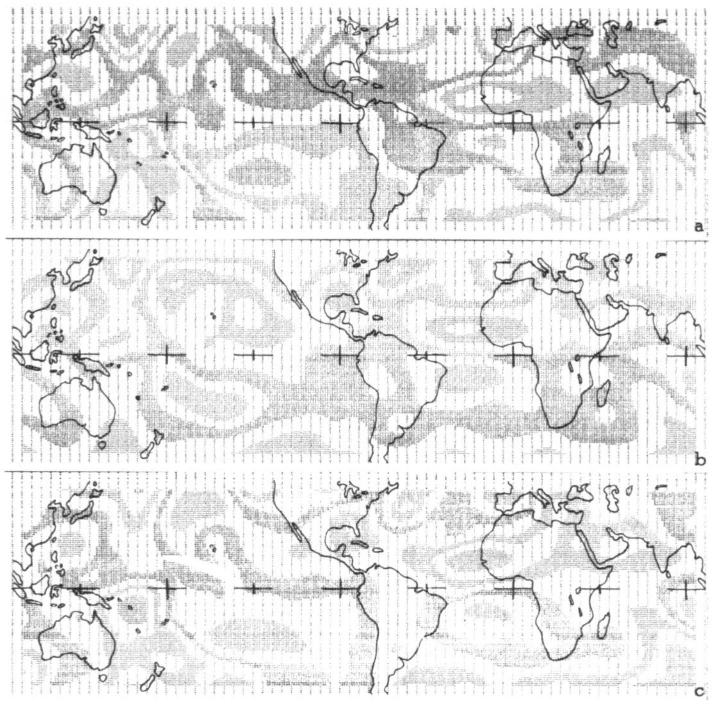

FIGURE 1.—(a) Initial streamfunction, 700 mb., 1200 GMT, April 8, 1967; (b) 24-hr. forecast; (c) verification.

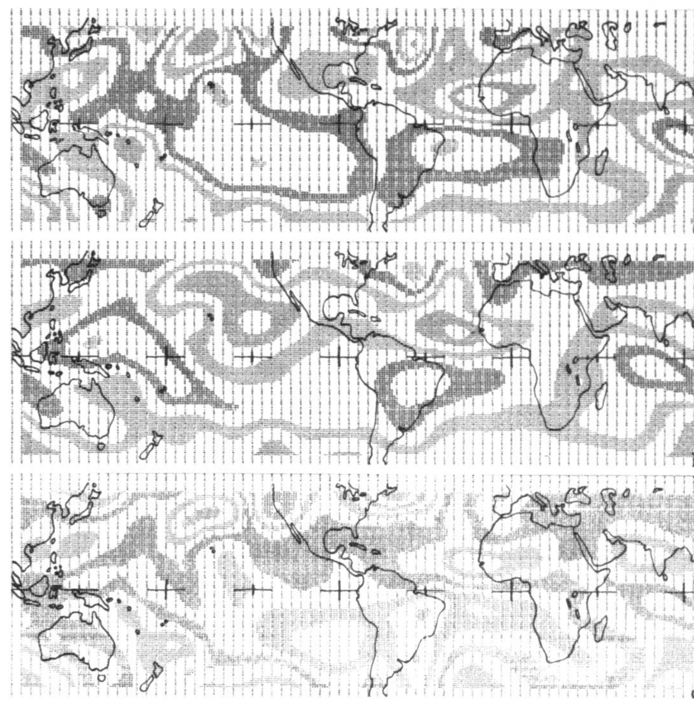

FIGURE 3.—(a) Initial streamfunction, 700 mb., 1200 GMT, April 10, 1967; (b) 24-hr. forecast; (c) verification.

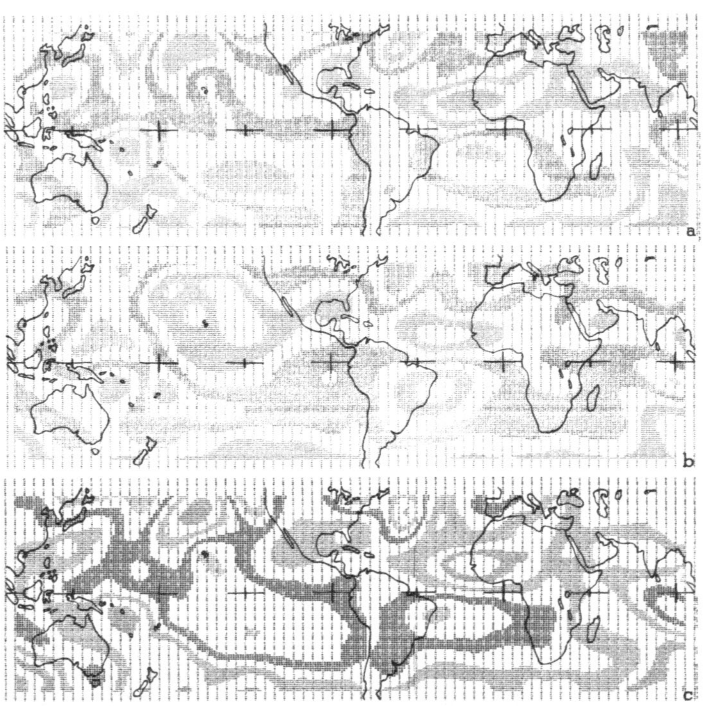

FIGURE 2.—(a) Initial streamfunction, 700 mb., 1200 GMT, April 9, 1967; (b) 24-hr. forecast; (c) verification.

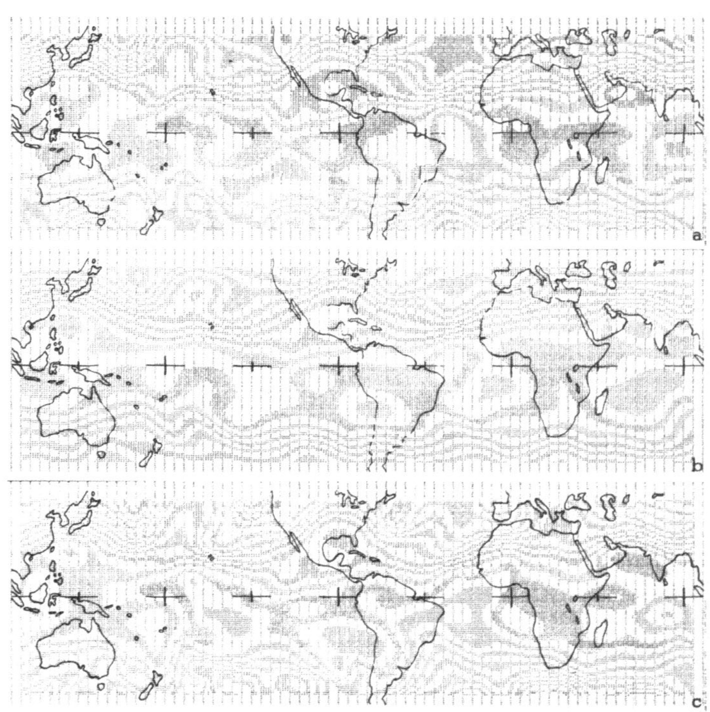

FIGURE 4.—(a) Initial streamfunction, 300 mb., 1200 GMT, April 8, 1967; (b) 24-hr. forecast; (c) verification.

of the mean vector error is 10 to 15 kt. at 700 mb. and 20 to 25 kt. at 300 mb. The forecast is slightly better than persistence for 700 mb. and is considerably better than persistence for 300 mb. This same error pattern has held in later verifications. For numerous reasons, verification against the wind analysis rather than the reported wind may introduce undetermined errors in the verification data. Visual verification of the forecasts seems to be more

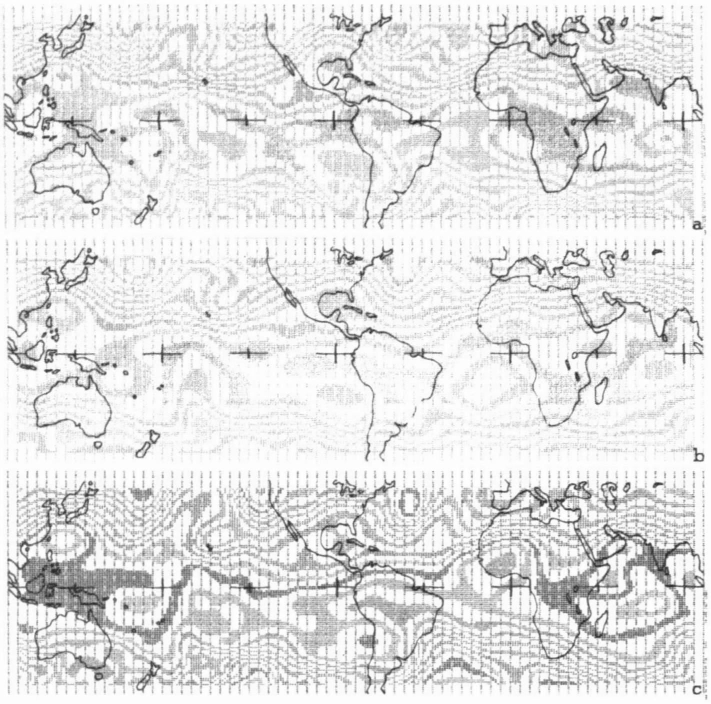

FIGURE 5.—(a) Initial streamfunction, 300 mb., 1200 GMT, April 9, 1967; (b) 24-hr. forecast; (c) verification.

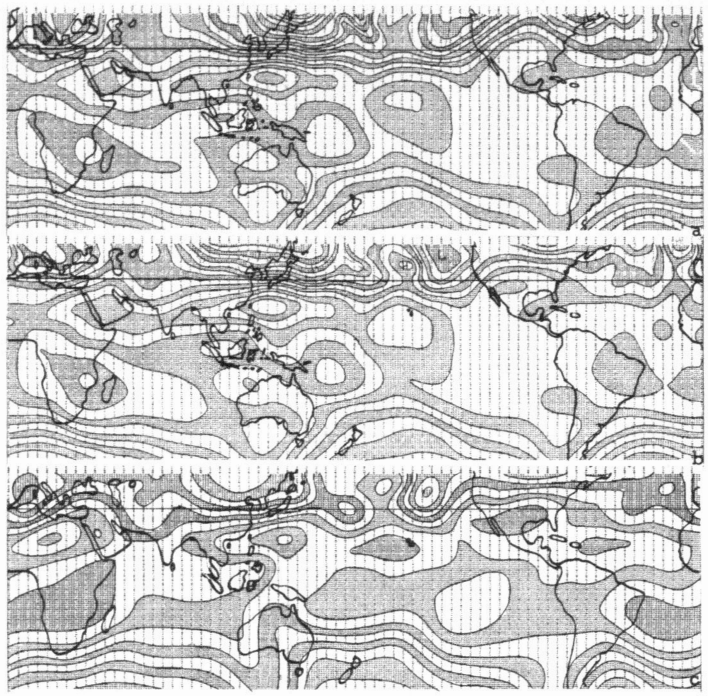

FIGURE 7.—(a) 36-hr. barotropic forecast streamfunction, valid 0000 GMT, November 19, 1966; (b) 36-hr. "meshed" barotropic forecast, valid 0000 GMT, November 19, 1966; (c) verification valid 0000 GMT, November 19, 1966.

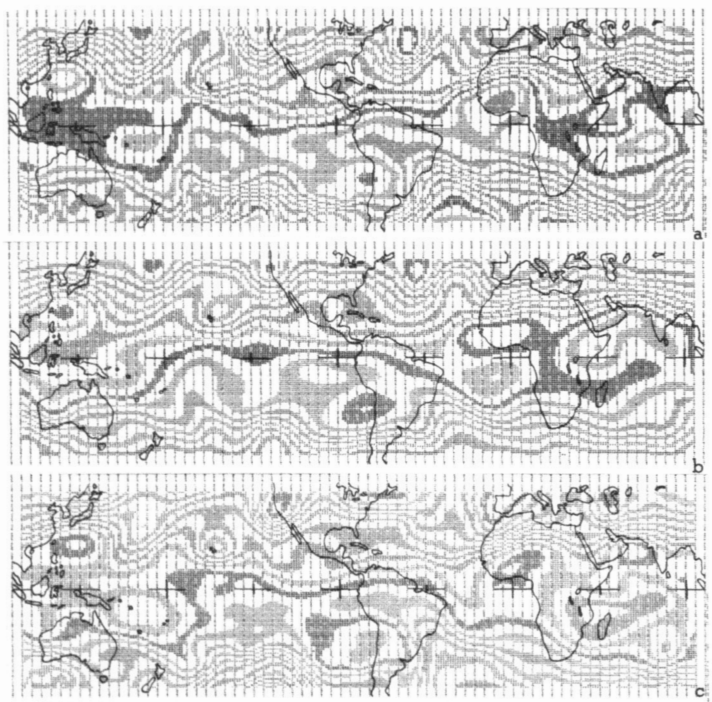

FIGURE 6.—(a) Initial streamfunction, 300 mb., 1200 GMT, April 10, 1967; (b) 24-hr. forecast; (c) verification.

definitive. Systems move in the correct direction but too slowly at 700 mb. in the higher latitudes. The 300-mb. forecasts at higher latitudes are generally good to excellent. The low latitude anticyclones frequently move westward too rapidly especially over southern Africa and South America in the forecasts; this is most noticeable at 700 mb. This latter type of error may be due to lack of data and, therefore, errors in the initial analysis.

Examples of forecasts are shown in figures 1 through 6. These are initial, 24-hr. forecast, and verifying streamfunction fields for April 8, 9, and 10, 1967, for both 700 mb. and 300 mb. Specific comments on some features of individual forecasts are:

a) In figure 1: The anticyclones over the Atlantic and the cyclone near Hawaii moved too far westward.

b) In figure 2: The anticyclone over the South Atlantic moved westward correctly. The trough over the southwest United States is too far east.

c) In figure 3: The cyclone near Hawaii is too far west. The anticyclone over South America moved correctly.

d) In figure 4: The anticyclone west of India was forecasted correctly to move eastward. The anticyclone near southwest Africa moved too far westward.

e) In figure 5: The cutoff Low near Hawaii and the trough and ridge positions over the United States are generally correctly forecasted.

f) In figure 6: Most individual systems are forecasted correctly.

## 4. MESHED TROPICAL FORECASTS

It was hoped that a relatively accurate high-latitude forecast could provide useful information to a forecast for the tropical region. For this reason, various forecasts for the high-latitudes have been used to specify the northern boundary conditions for both a primitive equation (PE) and filtered equation barotropic model. In interpreting the results, several factors should be taken into account, including the smoothness of the forecast, the accuracy near the boundary, the amount of change away from the boundary as a result of the meshing, and the usefulness of these changes.

The first attempts were to mesh a tropical PE barotropic forecast with a high-latitude PE barotropic forecast. In all cases the high-latitude forecasts have been calculated in advance, i.e., there was no interaction with the Tropics. The results of a PE mesh were entirely unsuccessful: near the boundary the systems were inaccurate and the changes to the Tropics resulted almost entirely from the incursion of gravity waves. All later attempts were made using the filtered equation barotropic model in the Tropics. Since many methods were attempted, most with some degree of success, only the better results will be discussed here. The most promising results were obtained by utilizing streams from a high-latitude forecast to define the stream tendency and vorticity at the boundary. It does not seem to matter whether these streams are obtained from a PE or filtered model, but height fields are not useful for specifying the boundary conditions without first solving the complete balance equation for streams.

Figure 7 shows a comparison of an unmeshed forecast at the top and meshed forecast below. There are rather large differences between the systems near the northern boundary and in all cases the meshed forecast represents an improvement. Some of the improvements may be enumerated:

a) The trough over Europe is retarded in the mesh forecast by strong vorticity advection to the west. This is in the correct direction, but in fact the trough moved even slower.

b) The Low in mid-Pacific is much better depicted in the mesh forecast. It was actually cutoff.

c) The High just to the east of the cutoff Low is moved northward by the unmeshed forecast; the shape and latitudinal placement in the meshed forecast is much better, but it has moved eastward too far.

d) The ridge-trough configuration over the United States is much improved in the meshed forecast.

In spite of all the above-mentioned improvements of the meshed forecast, few of these improvements lead to any significant changes south of 35°N. shown by the heavy line. For this reason, it is believed that most improvements in the 36-hr. forecasts as a result of meshing would be seen north of about 30°N. When the forecasts are used for flight plans, for instance, the improvement could still be useful.

## REFERENCE

1. F. G. Shuman and L. W. Vanderman, "Difference System and Boundary Conditions for the Primitive Equation Barotropic Forecast," *Monthly Weather Review*, vol. 95, No. 5, May 1966, pp. 329–335.

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